



Limitations in Production and Stocks and their Effect on the Profitability of the Slaughterhouses

Kjærsgaard, Niels Christian

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Kjærsgaard, N. C. (2008). *Limitations in Production and Stocks and their Effect on the Profitability of the Slaughterhouses*. Technical University of Denmark, DTU Informatics, Building 321. D T U Compute. Technical Report No. 2008-11

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Limitations in Production and Stocks and their Effect on the Profitability of the Slaughterhouses

Niels Kjærsgaard
Department of Management Engineering
Technical University of Denmark
2800 Lyngby
Denmark

March 31, 2008

Abstract

The pig industry is important for the Danish economy with an export value of more than DKK 28 billions in 2006 [Danish Meat Association (2007)] and the competition is increasing. Therefore it is more important than ever to optimize all aspects of Danish pig production, slaughtering processes and delivery.

This paper concerns the aspects of optimization at the slaughterhouses and addresses the modelling of physical logistic conditions. The description of the production processes and the logistic flow in this paper is primarily based on the conditions in one of the largest Danish slaughterhouses, used as model slaughterhouse.

The model is based on the model described in the paper regarding the value of a general increase in the slaughter weight for pigs [Kjærsgaard, N. (2008b)] but is more accurate by taking physical limitations at the slaughterhouses into consideration. The model is a Mixed Integer Programming (MIP) model and is used to estimate the costs of logistical limitations in the equalization room being the central cooling room where the carcasses should hang for a period of approx. 16 hours. Furthermore, the model is used to find economic effects of improved measurements as well as a general increase in the slaughter weight. This paper concerns the use of Operations Research to solve these practical problems, which is of major importance for the industry.

The cost of logistical limitations in the equalization room has been estimated to DKK 0.072 per kg or approximately DKK 145 million per year in total for the Danish slaughterhouses

The main conclusion is that even relatively simple optimization models can be used to improve the basis of the slaughterhouses for decision making considerably, both regarding computing the costs of having limitations in the production as well as the value of improved measurements and increased slaughter weight. Prices vary from one week to another, and consequently a price and cost study should be performed before the computations are used for actual decision support and more products and product alternatives should be included.

Estimations of the economic consequences of improved measurements and of a general increase in the slaughter weight have been improved among other things by taking the logistic limitations into consideration. Compared to the previous model regarding improved measurements [Kjærsgaard, N. (2008a)], the new model uses the entire pig and not just the middle piece. Furthermore, the weights of different products are estimated in much more detail based on the actual registered fat layer and the slaughter weight for each pig. Regarding increased slaughter weight, the model is now improved by taking the important logistic limitations into consideration.

1 Background

The pig industry is important for Danish Economy and exports. More than 25 million pigs were produced in Denmark in 2006, and approx. 90% of the meat was exported. The export value amounted to DKK 28.8 billion [Danish Meat Association (2007)].

Competition in the pork industry is substantial, and European farmers are pressed by increased feeding costs without having access to genetically modified crops as their American competitors. It is therefore more important than ever to optimize all aspects of Danish pig production and slaughtering processes.

Even from our neighbouring countries there is a substantial competition for the slaughterhouses to offer the best payments to the farmers, and during the last couple of years a substantial number of Danish farmers have started delivering part of their pigs to German slaughterhouses. It is therefore more important than ever to optimize all aspects of Danish pig production and slaughtering processes.

This paper concerns the aspects of optimization at the slaughterhouses, especially regarding the economic consequences of limitations in the production. Taking these limitations into consideration improves the estimation of the consequences of improved measurements and sorting, as well as the value of a general increase in the slaughter weight [Kjærsgaard, N (2008b)]. Operations Research methods are used to improve the decision support within these topics, which are of major importance for the slaughterhouse industry.

2 Literature survey

The literature regarding optimized raw material use at the slaughterhouses has been addressed in the paper “The Value of Improved Measurements in a Pig Slaughterhouse” [Kjærsgaard, N. (2008a)]. For convenience it is repeated here as this paper should be readable independently.

The amount of literature addressing improved or optimized raw material use in the food industry is substantial. However, the main part of the contributions is related to different aspects regarding either optimization of meat quality or different production processes. Examples of this are optimization of the industrial thermal sterilization of canned foods [Garcia, M. et. al. (2006)] and pigs stunning optimization [Dupuis, P. et. al. (2004)]. These types of optimizations are not relevant for this project as they are either based on statistical analysis without optimization of a mathematical model or the mathematical models are very different from the models, which are used in this Ph.D. project regarding optimization of the raw material use at the slaughterhouses.

Within the pork industry relatively few contributions have been found regarding optimization based on operations research methods. In the paper “Location of slaughterhouses under economies of scale” [Broek et. al. (2006)] optimization is used to investigate the savings potential of reducing the number of slaughterhouses in Norway and investing in additional capacity in the remaining facilities in order to obtain economies of scale. Another facility location problem is described in the paper “The impact of changes in livestock supply on the optimum number, size and location of slaughterhouses in East Macedonia” [Kamenidis, C. & Sorensen, V. (1978)]. In the paper “Economic optimization of pork production – marketing chains. II. Modelling outcome” [Ouden et. al. (1996)] are using Dynamic Linear programming to evaluate the development of pork chain concepts that also takes animal welfare into consideration. Kure in his Ph.D. thesis “Marketing Management Support in Slaughter Pig Production” [Kure, H. (1997)] uses Dynamic Programming to solve parts of the “slaughter pig

marketing management problem”, which regards how the farmers should select and market their pigs to the slaughterhouses.

The above mentioned four examples of optimization problems within the pork industry are all somewhat different from the problem of optimizing the raw material use at the slaughterhouses. More similar problems have been found in the following contributions:

In 1990-1992 a project regarding optimization of the raw material use at the slaughterhouses was performed as a cooperation between Danish Meat Research Institute and the Royal Veterinary and Agricultural University (now the Faculty of Life Sciences at University of Copenhagen). Several reports were made:

A Linear Programming (LP) model for production planning and control for the hog slaughterhouses was developed and reported in [Rasmussen, S. & Thomsen, M. (1991)] and [Rasmussen, S. (1992)]. The model is a 2-stage model. First stage concerns a planning horizon of 3 months and the second stage one weeks day to day planning. In [Fertin, C. (1992)] the long term planning model (stage 1) is validated.

In his Ph.D. thesis [Fertin [1995)] Fertin describes and further develops and validates the model.

There has been searched for literature in other food related industries, e.g. poultry and beef slaughterhouses and the fish industry, but no relevant literature has been found.

Other industries have similar problems as the slaughterhouses regarding its raw material use. An example is the refineries, but unlike the slaughterhouses the refineries have the option of blending different qualities in order to change the quality characteristics of the products. Another example is the lumber and wood industry. A few papers of the product mix problem within the wood industry have been identified. In the paper “An Optimization-Based Decision Support System for a Product Mix Problem” [Roy et. al. (1982)] an LP-model has been used to solve a plywood product mix problem for Ponderosa Industrial in Mexico.

Even though literature within food optimization is substantial, the main part of the contributions are related to optimization based on e.g. statistical analysis without optimization of a mathematical model. Other models are very different from the models used in this Ph.D. project. Except for the contributions from the Royal Veterinary and Agricultural University and the Danish Meat Research Institute not much literature of relevance for the Ph.D. project has been identified.

3 Limitations in production and stock

The slaughterhouse industry is characterized by the fact that the raw material (the pigs) in the short term exists in a given volume with a relatively varied quality and has a limited shelf-life. The raw material can be used for several different products, but to a large extent yields, prices and costs depend on how well the raw material in question fits the final products.

The slaughterhouses deal with the natural variation in quality, weight, size, fat layer, lean meat percentage, etc. by sorting the pigs into different sorting groups, in which pigs with almost the same characteristics are placed. However, the variation within each sorting group is still substantial due to the considerable measuring error in the current measuring systems as well as the limited number of sorting groups which the slaughterhouses are able to handle. Ideally, the slaughterhouses should be able to measure the quality without error and be able to handle an extensive number of sorting groups.

For the years to come it is expected that the measuring accuracy will be improved substantially. This will result in more pigs being placed in the correct sorting groups with less variation within each group as a consequence. If the full economic effect of improved sorting should be reached, more sorting groups are required. In general, the advantage of additional sorting groups increases when the measuring accuracy is improved.

As mentioned before a number of physical limitations influence the flow of raw materials in the slaughterhouses. Some of the most important are:

- The actual design of the equalization room.
- The number and design of the subsequent sorting places in the production.
- The design of the cold storage room used as buffer before cutting departments.

3.1 Production flow at the slaughterhouse

The production flow is almost the same at the different Danish slaughterhouses, but varies regarding capacities, e.g. the number of slaughter lines and bars in the equalization room. The description and the modelling are primarily based on the conditions at one of the largest Danish slaughterhouses, which is used as the model slaughterhouse.

The overall production flow at the model slaughterhouse can be seen in Figure 1 below and in a larger version in Appendix 2:

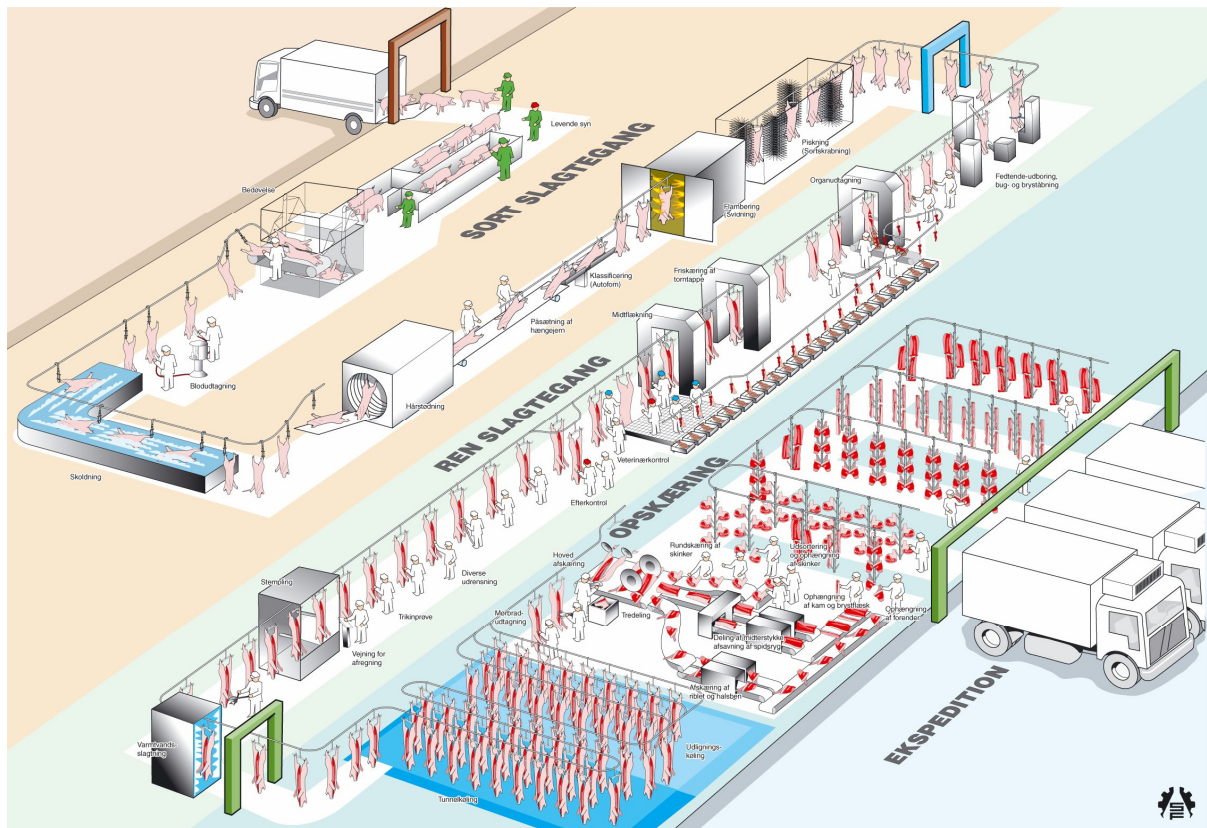


Figure 1. Production flow at the model slaughterhouse

The pigs are driven from the lairage area to one of the stunning centres with subsequent sticking and debleeding and continue at one of the four slaughtering lines to scalding, de-hairing and singeing.

The carcasses are cut open and heart, liver, kidney and intestines etc. are taken out. The carcasses are split in halves, but are still kept together by their jawbone. The carcass as well as heart, liver, kidney and intestines are inspected for diseases etc. If diseases are found, the carcass can be rejected or utilized for other purposes (e.g. as heat-treated products). The carcasses are cleaned and then weighted and graded in the classification centre. Here sundry measurements are performed, such as lean meat percentage and fat layer for the total carcass as well as for the individual main parts (fore end, middle piece

and ham). The weight, and other measurements as well as information about whether the pigs are special production pigs (e.g. Antonius or “welfare pigs” to the UK market) are of the utmost importance for the subsequent sorting of the carcasses. Each of the four slaughtering lines at the model slaughterhouse has a capacity of 350 pigs per hour, i.e. a total of 1,400 pigs per hour. The model slaughterhouse is only using 1 shift of approx. 8 hours at the slaughter lines.

After slaughtering, the carcasses are led through a freezing tunnel which quickly reduces temperature of the carcasses surfaces. Depending on predefined sorting groups the carcasses are placed on bars in the equalization room (cold storage), where they are hang for a period of minimum 16 hours to ensure a uniform temperature throughout the entire carcass. In general, these 16 hours will pass if the pigs are used for further processing the day after they have been slaughtered and placed at the equalization room.

The equalization room consists of 180 bars each with a capacity of 80 pigs. Each bar on which the carcasses are hung can only be emptied from the opposite side of the filling side, and consequently it has to be emptied in the same order as it was filled. See Figure 2 below:



Figure 2. Limitations in the equalization room.

For practical reasons whole bars are emptied at a time making it possible to dispose freely of the bars once more. The physical limitations in the equalization room (the number and capacity of the bars) are of the utmost importance for the number of active sorting groups that can be handled effectively. In practice, the slaughterhouses base the sorting on the middle piece and the ham, which are the most valuable parts of the pigs and hence the largest sorting potential. As the main parts (fore end, middle piece and ham) are not yet separated it is only possible to sort by one criterion which is primarily the middle piece. To some extent the sorting can be based on both the middle piece and

the ham at the same time, but the number of combinations (and the need for further sorting groups) increases rapidly thereby.

Due to logistic reasons the bars numbered 1 to 108 are primarily used for cutting line 1 and the bars from 109 to 180 for cutting line 2. To some extent, however, it is possible to relocate the carcasses at other bars, but that is a time consuming procedure which is not much used.

The placement in the equalization room is based on forecasts for how the pigs being slaughtered that day will be placed in sorting groups. The planning task here is to decide which bars should be allocated for different sorting groups. If possible, the carcasses are placed so that one bar consists of carcasses from only one sorting group and preferably from the same slaughtering day so the entire bar can be used in production at the same time for the same production batch. Sorting groups consisting of only few carcasses, for instance carcasses taken out for tests, damaged carcasses etc. may be mixed at the same bar due to space considerations. Due to quality and yield considerations it the carcasses should preferable be used for further processing the day after slaughtering and not stocked further at the equalization room

During the stay in the equalization room, each carcass has not yet been parted into the three main parts. This limits the possible number of sorting groups as a combinatorial “explosion” takes place. If there is e.g. 10 sorting groups for the middle piece, 10 for the ham and 3 for the fore end 300 sorting groups are required if any of these combinations should be possible. Therefore, in practice, a limited number of sorting groups can be handled and primarily based on the quality of the middle piece and only to some extent on the ham.

The number of active sorting groups can vary over time, but there are typically 15-20 main groups. In addition to these, there are approximately 30 smaller sorting groups for pigs with salmonella, diseases, pigs used in sundry experiments, special production pigs as well as damaged pigs or pigs with missing identification etc.

After 16 hours of placement in the equalization room, the carcasses are taken to one of the two cutting lines. Here the tenderloin and head are cut off and each half of the carcass is parted into three main parts: Fore end, middle piece and ham. The middle piece can further be split in two pieces and the middle piece and the ham can be sorted further by weight. The sorting by weight is automated, and the middle piece and the ham can be sorted separately into a maximum of 3 sorting groups each at a time.

At the end of the cutting line the parts are placed on stands each consisting of 20 items. The stands are placed in a buffer storage before they are taken to different cutting departments for further processing. After further processing the products are packed and delivered to the customers.

4 The Model

The purpose of the model is to estimate the costs of having certain limitations in the production as well as improving previously developed models [Kjærsgaard, N. (2008a, b)] used to estimate the economic effects of improved measurements and increased slaughter weight. The costs or benefits are found by performing two optimizations, one under current conditions and one under improved conditions. The improvement can then be found as the difference between the profits of the two optimizations.

4.1 Description of the Model

As mentioned before there are a number of logistic limitations at the slaughterhouses. The most important concerns the equalization room, where the temperature of the pigs is equalized through the entire carcass. In the slaughterhouse used as basis for the modelling the carcasses are placed in the equalization room on bars containing 80 carcasses each. Each bar can only be emptied from the opposite side of the filling side. In principle, carcasses placed on the same bar are therefore used to produce the same production orders (the same package of products). This limitation is considered to be the most important logistic limitation, but the model can be extended to include more of the limitations described in Chapter 3.

The model is based on the model described in paper B [Kjærsgaard, N. (2008b)] but is repeated here in order to make this paper readable independently. In the experiments we use the actual slaughtering data from 43,949 pigs slaughtered at one of the Danish slaughterhouses. For each pig the registered fat layer and the actual slaughter weight are used. In the computations the registered fat layer is considered the true value. When performing computations regarding improved measurements and sorting, a simulated measuring error is added to the registered fat layer and then considered the measured fat layer. For computations regarding increased slaughter weight, in general there is coherence between slaughter weight and the size of the fat layer. When the slaughter weight is increased by 1 kg, the fat layer is increased with approx. 0.16 mm [Kjærsgaard, N. (2008b)].

The model has its basis in different alternative uses of the pigs. Each alternative use consists of a “package” of products for the specific part. The back and the ham have two alternative uses each and the fore end has one. In total there are four different alternative uses for each pig. In total, 17 different main products are used, but the model can easily be modified to include more products and alternative uses.

The different alternative uses for different parts of the pigs can be seen in Figure 3 below:

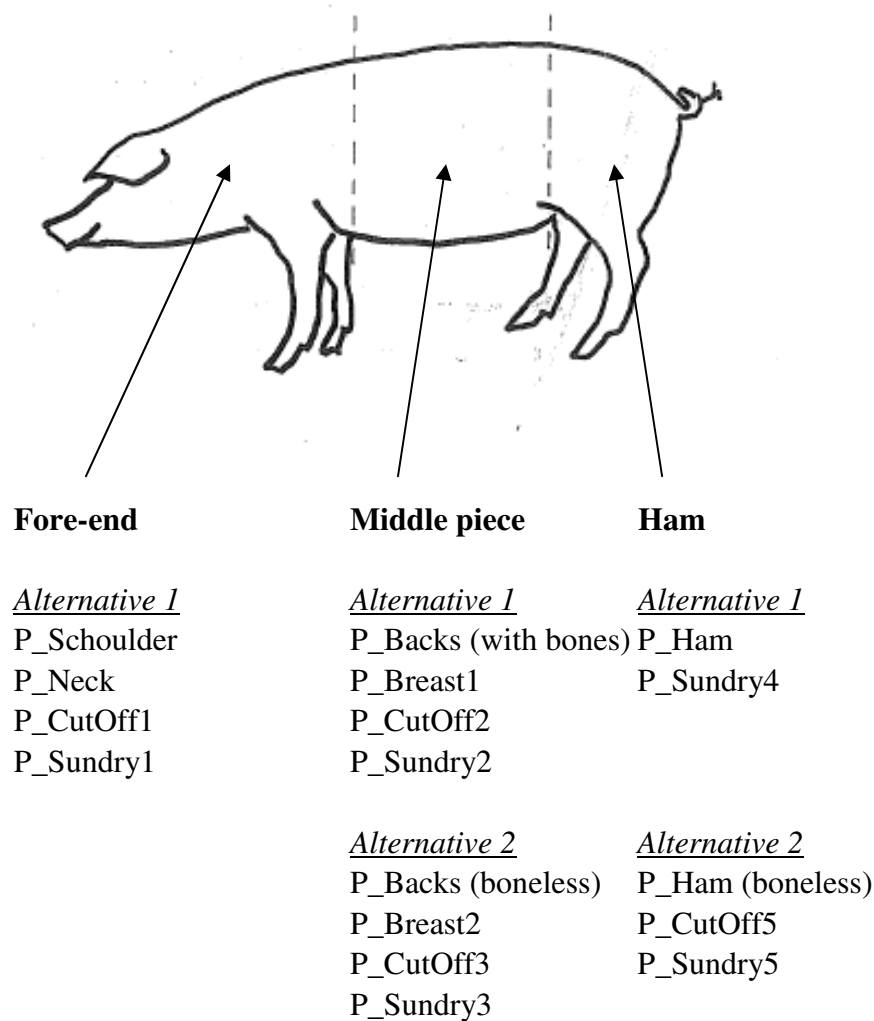


Figure 3. Alternative uses of the pigs.

Some raw materials (pigs) are better suited for some products than others. This is taken into consideration when increasing or decreasing the price for some products depending on

the level of the fat layer. In the model, this is done by splitting the pricing in two different contributions:

1. A fixed price per kg for the given product
and
2. A price coefficient, which stipulates how much the price will decrease if the fat layer increases by 1 mm.

For two of the products there are a few special additional conditions which have to apply in order for the raw materials to be used for these products:

- The ham product P_Ham can only be produced if the fat layer does not exceed 14 mm
and
- The breast product P_Breast2 can only be produced if it does not exceed a weight of 4 kg.

If these conditions are not met, a penalty is introduced in the prices. The penalty cover additional handling costs if these raw materials should be used for other products instead.

The products P_CutOff (1, 2, 3, 5) consist of meat cut-offs in connection with production of the main products, and products P_Sundry (1-5) consist of fat, bones, rind etc.

4.2 Mathematical Formulation of the Model

We have a set of carcasses $\mathcal{I}=\{1,...,I\}$. Each carcass can be used to produce a set of different product alternatives $\mathcal{N}=\{1,...,N\}$ and each product alternative consists of a set of different products $\mathcal{J}=\{1,...,J\}$. Finally the carcasses are hung on bars $\mathcal{K}=\{1,...,K\}$ in the equalization room. The decision variable $y_{k,n}$ is a binary variable with the value 1 if the pigs placed on bar k are used to produce product alternative n and otherwise 0. The problem is to find the optimal utilization (product alternatives) of the carcasses placed at each bar and the total profit for the optimal solution:

The objective function:

$$1) \text{ Maximize } Z = \sum_{k,n} \text{ValueBar}_{k,n} \bullet y_{k,n}$$

Subject to:

$$2) \sum_n y_{k,n} = 1 \quad \forall k \in \mathcal{K}$$

$$3) y_{k,n} = \{1 \text{ if product alternative } n \text{ is produced by pigs placed on bar } k, \text{ otherwise } 0\}$$

$$4) \text{ValuePig}_{i,n} = \sum_{i,n} (\text{Price}_j + \text{PriceCoeff}_j \bullet \text{FatLayerDeviation}_i - \text{QualityDeduction}_{i,j}) \bullet \text{ProdWeight}_{i,j} \bullet \text{AltUse}_{j,n}$$

$$5) \text{ValueBar}_{k,n} = \sum_k \text{ValuePig}_{k,n}$$

Indices:

i : pig i k : bar k j : product j n : alternative use n

Decision variables:

$y_{k,n}$: Decision variable with value 1 if the carcasses placed on bar k are used for product alternative n , otherwise 0.

Parameters:

$\text{ValueBar}_{k,n}$: Value of the carcasses placed on bar k when used to produce alternative n .

$\text{ValuePig}_{i,n}$: Value of carcass i , when producing alternative n .

Price_j : Fixed net price per kg for producing product j .

PriceCoeff_j : Change in net price per kg for product j when the fat layer increases by 1 mm.

$\text{FatLayerDeviation}_i$: Deviation in the fat layer of carcass i compared to the average fat layer.

$\text{QualityDeduction}_{i,j}$: Price deduction per kg if quality demands are not being met when carcass i is used for production of product j .

$\text{ProdWeight}_{i,j}$: Estimated weight of product j , when produced from carcass i .

$\text{AltUse}_{j,n}$: Alternative use (product package) with value 1 if product j is part of product alternative n , otherwise 0.

The objective function (1) maximizes the sum of the value of carcasses at each bar by finding the best alternative use for each bar when all carcasses placed on the same bar are used for the same product alternative. The constraint (2) controls that the carcasses placed at each bar are only used once. The model uses a number of different parameters. The most important ones are shown in (4) and (5) and are either directly or indirectly used in the

objective function. The parameter $ValuePig_{i,n}$ (4) finds the value of each carcass i , when producing product alternative n . The value is based on a price per kg for each potential product, a price coefficient depending on the fat layer and a deduction in price if certain quality measurements are not met. This net price for different products is multiplied with the estimated weight of the products. The parameter $ValueBar_{k,n}$ finds the total value of carcasses placed at bar k , when producing product alternative n .

5 Results

In this chapter, the model is used to compute the economic consequences of having limitations in the production, improving the measurements at the slaughterhouses and a general increase in the slaughter weight.

5.1 Limitations in the Production

The economic consequences of having limitations in the equalization room are found by performing two optimizations and comparing the results. The model described in the previous chapter is used to find the optimal alternative use (product package) of the carcasses placed on each bar and the profit hereof. The computation takes the limitations in the equalization room into consideration. Without these limitations it corresponds to that the cooling room is a random access cooling room from where each carcass can be taken out for the production in any order required. When finding the profit without limitations in the equalization room the following slightly modified mathematical model is used:

The objective function:

$$1a) \quad \text{Maximize } Z = \sum_{i,n} ValuePig_{i,n} \bullet y_{i,n}$$

Subject to:

$$2a) \quad \sum_n y_{i,n} = 1 \quad \forall i \in \mathcal{I}$$

$$3a) \quad y_{i,n} = \{1 \text{ if product alternative } n \text{ is produced of pig } i, \text{ otherwise } 0\}$$

The parameter $ValueBar_{k,n}$ (5) used in the model described in the previous chapter is not necessary in this optimization and the parameter $ValuePig_{i,n}$ (constraint 4) remains unchanged.

$$4) \quad ValuePig_{i,n} = \sum_{i,n} (Price_j + PriceCoeff_j \cdot FatLayerDeviation_i - QualityDeduction_{i,j}) \cdot ProdWeight_{i,j} \cdot AltUse_{j,n}$$

Index k for bars is no longer necessary, but the other indices i, j and n remain unchanged.

For the 43,949 pigs being part of the experiment, the costs of having limitations are computed and can be seen in Table 1 below:

	DKK
Profit with no limitations	38,243,284
Profit with limitations	<u>37,987,026</u>
Cost of limitations	256,258
Cost of limitations per kg	<u>0,072</u>

Table 1. Cost of having limitations in the equalization room (in DKK)

In the experiment, the pigs have been placed in 65 different sorting groups based on the estimated measured fat layer in intervals of 0.5 mm. The number of sorting groups is considerably larger than used by the slaughterhouses today.

If a much smaller number of sorting groups were used in the experiment, the computed costs of the limitations would be increased. The computed profit with limitations would decrease and the profit with no limitations would remain unchanged (see Table 1 above). However, by designing the sorting strategies in a more intelligent way (see [Kjærsgaard, N. (2008d)]) the increase in costs can be limited.

The model can also be used to find economic consequences of improved measurements as well as a general increase in slaughter weight.

5.2 Improved measurements

In Table 2 below, the economic consequences of improving the measuring accuracy by 20% can be seen. This means that the standard error of prediction (SEP) of the fat layer is decreased by 20% from its current level of 1.28 mm to 1.02 mm.

Measuring accuracy	Profit (DKK)
Improved with 20% (SEP 1.02)	37,909,314
Current (SEP 1.28)	37,875,591
Improvement	33,723

Table 2. Improvement in the profit due to increased measurements (SEP decreased by 20%)

As it can be seen, the profit increases by DKK 33,723 for the 43,949 pigs used in the experiment. This equals DKK 0.77 per pig or approx. DKK 19 million per year for the Danish slaughterhouses. Similar computations have been carried out for other sizes of improvements and can be seen in Figure 4 below:

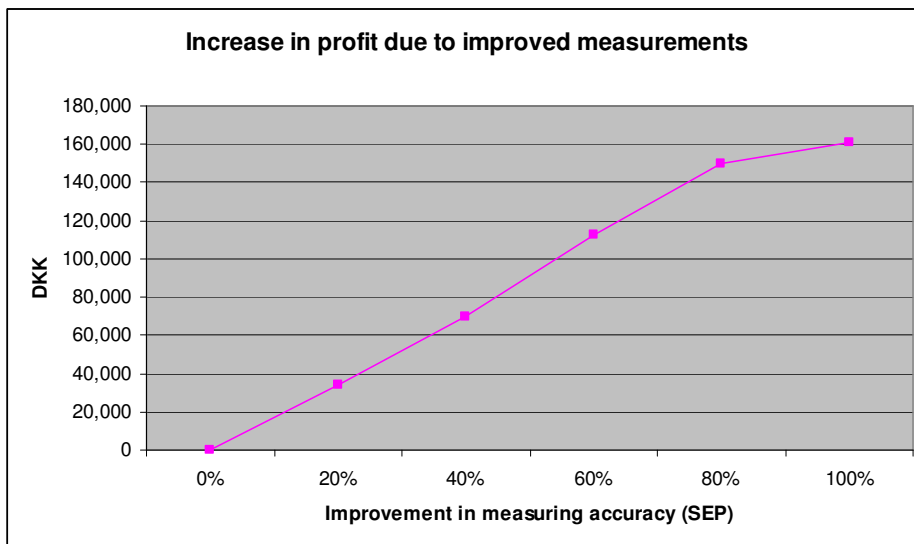


Figure 4. Increase in profit due to improved measurements (for the 43,949 pigs)

As can be seen in figure 4 above, the effect is almost linear up to an improvement in the measuring accuracy of 80% after which the improvement declines.

5.3 Increased slaughter weight

As mentioned before, the model can also be used to compute the economic consequences of increased slaughter weight. The result of the experiment can be seen in Table 3 below:

	Current weight	Plus 5 kg
Profit in DKK	37,875,592	39,270,690
Profit improvement (DKK)		1,395,098
Production in kg	3,576,982	3,796,727
Average price per kg	10.589	10.343
Change in average price (DKK)		-0.245

Table 3. Improvement in profit due to a general increase in slaughter weight by 5 kg.

It can be seen that the profit for the 43,949 pigs used in the experiments increases by 3.7% (DKK 1,395,098) when the slaughter weight is increased by 5 kg. This increase in slaughter weight is equivalent to a 6.1% increase in the production volume and the average price per kg will decrease by 2.3% or DKK 0.245. Some of the costs at the slaughterhouses as well as at the farmers are, however, fixed or variable according to the number of pigs produced instead of according to the production in terms of weight. Therefore, the decrease in average prices should be compared to the cost savings in the slaughterhouses and at the farmers. These savings have previously been estimated to approx. DKK 0.15 and DKK 0.10 respectively for an increase in the slaughter weight of 5 kg [Mønsted, K. (2006)]. Taking these savings into account, the computations show that a minor increase in the total profits of the slaughterhouses and the farmers can be expected if the slaughter weight is increased. However, the increase in profits is small and the net prices used are for illustrative purposes. There is a natural variation in prices over time. As the market situation changes continuously it has not been possible to have access to the latest prices, but information of typical prevailing prices have been received from the Danish slaughterhouses. Therefore a price study should be performed before the computation should be used for actual decision making. In the next chapter potential improvements of the model and in the data used are discussed further. See the paper [Kjærsgaard, N. (2008b)] for further information regarding the consequences of increased slaughter weight.

The GAMS code for the model can be seen in Appendix 1. The model has 178,696 constraints and 3,980 variables and was solved to optimality in just 18 seconds which is considered very acceptable. See chapter 4.2 in the thesis [Kjærsgaard, N. (2008e)] for further information regarding solution times.

6 Discussions

The models presented in this paper have been used to illustrate how Operations Research can be applied to improve the slaughterhouses basis for decisions. The models can be used to estimate the costs of having logistic limitations at the slaughterhouses and is also an improvement compared to the previous models described in papers regarding improved measurements and increased slaughter weight [Kjaersgaard, N. (2008a, b)]. Prices vary over time and consequently a price and cost study should be performed before the computations are used for actual decision support.

In order to be able to use the model for actual decision making the prices and cost as well as product yields should be studied further. The study should include how all these factors are influenced by changes in slaughter weight and other quality characteristics, such as fat layer, lean meat percentage etc.

The model can be improved in a number of ways:

- Increasing the number of products and product alternatives. In this paper the model is illustrated by using 17 main products and four product alternatives. In order to receive as reliable results as possible, all essential products and product alternatives should be used. See the Ph.D. thesis [Kjaersgaard, N. (2008e)] for further information regarding the complexity of such an increase in the number of products and products alternatives.
- Extending the model with more logistic limitations, e.g. the automatic sorting by weight of the middle piece and the ham and the limitations at the buffer storage. This requires that the number of product alternatives is much larger than the current four.
- Extending the model with maximum and minimum sales volumes of different products. For some of the products the slaughterhouses can only sell a certain volume. This is especially the case in the short and medium term where the slaughterhouses have entered into contracts to deliver a certain volume. These situations can be modelled by having constraints regarding the sales of each product.
- Performing a study of the prices and costs of producing and selling different products. The study should be performed by the slaughterhouses, as the information is considered very sensitive. See paper regarding improved measurements for further information regarding prices and costs [Kjaersgaard, N. (2008a)].
- Using the actual sorting groups and criteria, which the slaughterhouses use today, to estimate the current level of profit (and use this as a basis to compare any

improvements/changes). This requires the number of products and product alternatives to be much larger than the current numbers used in the computations.

7 Conclusion

The costs of having logistic limitations in the equalization room have been estimated using Mixed Integer Programming.

Even though only four different product alternatives are used (two for the middle pieces and two for the ham) the computations show that the cost of logistic limitations in the equalization room is considerable. The cost of having these logistic limitations has been estimated to DKK 256,258 for the 43,949 pigs used in the experiment. This equals DKK 0.072 per kg or approximately DKK 145 million annually for Danish slaughterhouses. The fact that the computations are only based on 17 main products and four alternative uses is likely to underestimate the profit. When taking the constraints regarding placement on bars into consideration more products and product alternatives will increase the share of pigs which are no longer used optimally. This will increase the computed costs. Furthermore, the average costs for each pig not being used optimally may increase too as the spread between optimal and poor utilization of the pig is likely to increase. On the other hand, some of these additional costs can be saved by sorting the middle piece and ham by weight later in the production process.

The economic consequence of improving the measuring accuracy by e.g. 20% is an increase in profit by DKK 33,723 for the 43,949 pigs used in the experiments. This equals DKK 0.77 per pig or approximately DKK 19 million annually for the Danish slaughterhouses. It can be seen in figure 5 below that the effect is almost linear up to an improvement in the measuring accuracy by 80% after which the increase in profits decline:

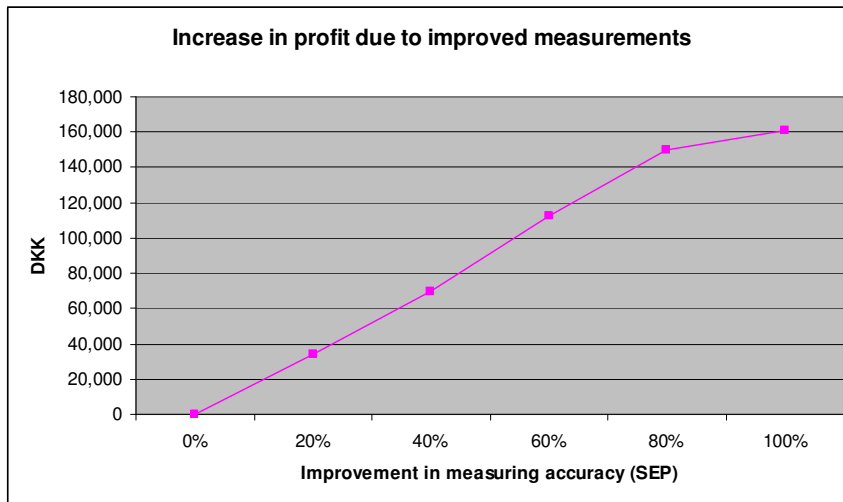


Figure 5. Increase in profit due to improved measurements (for the 43,949 pigs)

The economic consequences of increased slaughter weight have been computed. The average price per kg produced meat decreases with DKK 0.245 when the slaughter weight increases by 5 kg. This should be compared to the cost saving in the slaughterhouse and at the farmers. These savings has previously been estimated to DKK 0.15 and DKK 0.10 respectively for an increase in the slaughter weight of 5 kg [Mønsted, K. (2006)].

Compared to the previous models described in the two papers [Kjærsgaard, N. (2008a, b)] regarding the value of improved measurements and a general increase in the slaughter weight, the accuracy of the model has been improved by taking the logistic limitations in the equalization room into consideration.

The main conclusion is that even relatively simple optimization models can improve the basis of the slaughterhouses for decision making considerably in connection with finding the value of logistic changes in the production, improved measurements and increased slaughter weight. Before using the model as actual decision support, the accuracy of the model can be further improved by:

- Increasing the number of products and product alternatives, so that most of the products produced by the slaughterhouses are covered.
- Extending the model with more logistic limitations, e.g. the automatic sorting by weight of the middle piece and ham and the buffer storage (requires that the number of product alternatives is much larger than the current four).

- Extending the model with maximum and minimum sales volumes of different products.
- Performing a study of the prices and costs of selling and producing different products. The study should be performed by the slaughterhouses, as the information is considered very sensitive.
- Using the sorting groups and criteria, used by the slaughterhouses today, to estimate the current level of profit (and use this as a basis of comparing new computations).

Bibliography

Broek et. al. (2006). Location of slaughterhouses under economies of scale. *European Journal of Operational Research* 175 (2006 740-750).

Danish Meat Association (2007). Danske Slagterier. Statistics 2006 – pigs.

Dupuis, P. et. al. (2004). Pigs Stunning Optimisation. Instrumentation and Measurement Technology Conference, Como, Italy.

Fertin, C. (1992). Validation of long term planning model for optimization of the raw material use at pig slaughterhouses (in Danish). The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Fertin, C. (1995). The use of a multi-Periodic LP-Model as Basis for a Decision Support System for Pig Slaughterhouses (in Danish). Ph.D. Thesis (Lic. 1239), The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Garcia, M. (2006). Computing optimal operating policies for the food industry. *Journal of Food Engineering* 74 (2006 13-23).

Hillier, F & Lieberman, G. (2001). *Introduction to Operations Research*. Seventh Edition. McGraw-Hill International Editions.

Kamenidis, C. & Sorensen, V. (1978). European Review of Agricultural Economics (1978-5 143-158).

Kjærsgaard, N. (2008a). The Value of Improved Measurements in a Pig Slaughterhouse. Technical Report, Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kjærsgaard, N. (2008b). The Value of a General Increase in Slaughter Weight for Pigs. Technical Report, Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kjærsgaard, N. (2008c). Limitations in Production and Stock and their effect on the Profitability of the Slaughterhouses. Technical Report, Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kjærsgaard, N. (2008d). Evaluating Different Sorting Criteria and Strategies using Mathematical Programming. Technical Report, Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kjærsgaard, N. (2008e). Optimization of the Raw Material Use at the Danish Slaughterhouses. Ph.D. thesis. Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kure, H. (1997). Marketing Management Support in Slaughter Pig Production. Ph.D. Thesis (Dina Research Rapport No. 57), The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Mønsted, K. (2006) Slaughterhouse costs at increased slaughter weight (in Danish). Internal presentation. Danish Meat Research Institute.

Ouden et. al. (1996). Economic optimization of pork production – marketing chains. II. Modelling outcome. *Livestock Production Science* 48 (1997 39-50).

Rasmussen, S. & Thomsen, M. (1991). A Model for Optimizing of the Raw Material Use at Pig Slaughterhouses. The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Rasmussen, S. (1992), The use of a multi-period LP-model as the core of a Decision Support System for a hog slaughterhouse. The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Roy et. al. (1982). An Optimization-Based Decision Support System for a Product Mix Problem. *The Institute of Management Sciences*, vol. 12, no. 2, April 1982.

Wolsey, L. (1998). *Integer Programming*. John Wiley & Sons, Inc.

Appendix 1 – GAMS code

```

* CanneryTransport.gms
*
* CanneryTransport.gms
*
$solcom //
option iterlim=999999999; // avoid limit on iterations
option reslim=300; // timelimit for solver in sec.
option optcr=0.0; // gap tolerance
option solprint=OFF; // include solution print in .lst file
option limrow=100; // limit number of rows in .lst file
option limcol=100; // limit number of columns in .lst file
//-----

SETS
  i  Pigs i / p1*p43949/
  j  Products / P_Schoulder, P_Neck, P_Backs (with bones), P_Breast1, P_Backs (boneless),
               P_Breast2, P_Ham, P_Ham (boneless), P_CutOff1, P_CutOff2,
               P_CutOff3, P_CutOff5, P_Sundry1, P_Sundry2, P_Sundry3,
               P_Sundry4, P_Sundry5, P_moerbrad, P_hoved, H_8201 /
  s(j) Products sold / P_Schoulder, P_Neck, P_Backs (with bones), P_Breast1, P_Backs (boneless),
                      P_Breast2, P_Ham, P_Ham (boneless), P_CutOff1, P_CutOff2,
                      P_CutOff3, P_CutOff5, P_Sundry1, P_Sundry2, P_Sundry3,
                      P_Sundry4, P_Sundry5, P_Tenderloin, P_Head /
  l  Bar l / Bar1*Bar585 /
  n  Product Alternative n / Alt1*Alt4 /

$Include weight_5_SG100_fordeling_stænger_65SG.txt
;

PARAMETER
  Price(j) Price per kg for products j
  /
    P_Schoulder 12.00
    P_Neck 13.00
    P_Backs (with bones) 18.00
    P_Breast1 13.00
    P_Backs (boneless) 25.00
    P_Breast2 17.00
    P_Ham 15.00
    P_Ham (boneless) 18.00
    P_CutOff1 9.00
    P_CutOff2 9.00
    P_CutOff3 9.00

```


P_CutOff5	9.00
P_Sundry1	3.00
P_Sundry2	3.00
P_Sundry3	3.00
P_Sundry4	3.00
P_Sundry5	3.00
P_Tenderloin	30.00
P_Head	3.00
H_8201	0.00

/

PriceCoeff(j) Price Coefficient (in DKK) for product j for an increase of layer of fat (in mm)

/ P_Soulder	0.00
P_Neck	0.00
P_Backs (with bones)	-0.20
P_Breast1	-0.20
P_Backs (boneless)	-0.20
P_Breast2	-0.20
P_Ham	-0.20
P_Ham (boneless)	-0.20
P_CutOff1	-0.10
P_CutOff2	-0.10
P_CutOff3	-0.10
P_CutOff5	-0.10
P_Sundry1	0.00
P_Sundry2	0.00
P_Sundry3	0.00
P_Sundry4	0.00
P_Sundry5	0.00
P_Tenderloin	0.00
P_Head	0.00
H_8201	0.00

/

ProdWeightCon(j) Product weight constant for product j

/ P_Soulder	0.00000
P_Neck	0.00000
P_Backs (with bones)	10.77058
P_Breast1	2.00642
P_Backs (boneless)	0.46036
P_Breast2	2.00642
P_Ham	0.00000
P_Ham (boneless)	-1.11490
P_CutOff1	0.00000
P_CutOff2	0.00000
P_CutOff3	0.00000
P_CutOff5	0.00000
P_Sundry1	-1.95414

P_Sundry2	-14.54192
P_Sundry3	0.00000
P_Sundry4	0.00000
P_Sundry5	0.00000
P_Tenderloin	1.20000
P_Head	0.00000
H_8201	-1.58570

/

ProdWeightFat(j) Product weight fat dependend coefficient for product j

/ P_Schoulder	-0.06938
P_Neck	-0.04096
P_Backs (with bones)	-0.01662
P_Breast1	0.04284
P_Backs (boneless)	- 0.08124
P_Breast2	0.04284
P_Ham	-0.10204
P_Ham (boneless)	-0.19054
P_CutOff1	-0.00596
P_CutOff2	-0.00596
P_CutOff3	-0.00596
P_CutOff5	-0.00596
P_Sundry1	0.07922
P_Sundry2	0.11178
P_Sundry3	0.00000
P_Sundry4	0.00000
P_Sundry5	0.00000
P_Tenderloin	0.00000
P_Head	0.00000
H_8201	-0.10160

/

\$Include FatLayer_beg.txt

\$Include PigWeight_beg.txt

ProdWeightWeight(j) Product weight slaughtering weight dependent coefficient for product j

/ P_Schoulder	0.10726
P_Neck	0.07282
P_Backs (with bones)	0.01354
P_Breast1	0.06002
P_Backs (boneless)	0.08666
P_Breast2	0.06002
P_Ham	0.27632
P_Ham (boneless)	0.22874
P_CutOff1	0.00834
P_CutOff2	0.00834

P_CutOff3	0.00834
P_CutOff5	0.00834
P_Sundry1	0.13368
P_Sundry2	0.24410
P_Sundry3	0.00000
P_Sundry4	0.00000
P_Sundry5	0.00000
P_Tenderloin	0.00000
P_Head	0.00000
H_8201	0.29790

/

;

Table Anvendelse(j,n) Product alternative n in which product j is part of

	Alt1	Alt2	Alt3	Alt4
P_Schoulder	1	1	1	1
P_Neck	1	1	1	1
P_Backs (with bones)	1	1	0	0
P_Breast1	1	1	0	0
P_Backs (boneless)	0	0	1	1
P_Breast2	0	0	1	1
P_Ham	1	0	1	0
P_Ham (boneless)	0	1	0	1
P_CutOff1	1	1	1	1
P_CutOff2	1	1	0	0
P_CutOff3	0	0	1	1
P_CutOff5	0	1	0	1
P_Sundry1	1	1	1	1
P_Sundry2	1	1	0	0
P_Sundry3	0	0	1	1
P_Sundry4	1	0	1	0
P_Sundry5	0	1	0	1
P_Tenderloin	1	1	1	1
P_Head	1	1	1	1
H_8201	0	0	0	0

;

Parameter ProdWeight(j,i) Weight of product j from pig i ;

ProdWeight(j,i) = ProdWeightCon(j) + ProdWeightFat(j)*FatLayer(i) +
ProdWeightWeight(j)*PigWeight(i) ;

ProdWeight('P_Sundry3',i) = ProdWeight('P_Backs (with bones)',i) + ProdWeight('P_Breast1',i) +
ProdWeight('P_CutOff2',i)
+ ProdWeight('P_Sundry2',i) - ProdWeight('P_Backs (boneless)',i)
- ProdWeight('P_Breast2',i) - ProdWeight('P_CutOff3',i) ;

$\text{ProdWeight}('P_Sundry4',i) = \text{ProdWeight}('H_8201',i) - \text{ProdWeight}('P_Ham',i) ;$

$\text{ProdWeight}('P_Sundry5',i) = \text{ProdWeight}('H_8201',i) - \text{ProdWeight}('P_Ham (boneless)',i) - \text{ProdWeight}('P_CutOff5',i) ;$

$\text{ProdWeight}('P_hoved',i) = \text{PigWeight}(i) - \text{ProdWeight}('P_Shoulder',i) - \text{ProdWeight}('P_Neck',i) - \text{ProdWeight}('P_Backs (with bones)',i) - \text{ProdWeight}('P_Breast1',i) - \text{ProdWeight}('P_Ham (boneless)',i) - \text{ProdWeight}('P_CutOff1',i) - \text{ProdWeight}('P_CutOff2',i) - \text{ProdWeight}('P_CutOff5',i) - \text{ProdWeight}('P_Sundry1',i) - \text{ProdWeight}('P_Sundry2',i) - \text{ProdWeight}('P_Sundry5',i) - \text{ProdWeight}('P_Tenderloin',i) ;$

Parameter QualityDeduction(j,i) Deduction in price at product weight above 3.5 kg per back (7 kg per pig) and requirement for breast and ham ;

$\text{Fradrag}('P_Backs (with bones)',i) = 2\$(\text{ProdWeight}('P_Backs (with bones)',i) \text{ gt } 7) + 0\$(\text{ProdWeight}('P_Backs (with bones)',i) \text{ le } 7) ;$

$\text{Fradrag}('P_Backs (boneless)',i) = 2\$(\text{ProdWeight}('P_Backs (boneless)',i) \text{ gt } 7) + 0\$(\text{ProdWeight}('P_Backs (boneless)',i) \text{ le } 7) ;$

$\text{Fradrag}('P_Breast2',i) = 6\$(\text{ProdWeight}('P_Breast2',i) \text{ gt } 8) + 0\$(\text{ProdWeight}('P_Breast2',i) \text{ le } 8) ;$

$\text{Fradrag}('P_Ham',i) = 4\$(\text{FatLayer}(i) \text{ gt } 14) + 0\$(\text{FatLayer}(i) \text{ le } 14) ;$

Parameter ValueGris(i,n) Price for pig i at alternative use n ;

$\text{ValueGris}(i,n) = \text{sum}(j, (\text{Price}(j) - \text{Fradrag}(j,i) + \text{PriceCoeff}(j) * (\text{FatLayer}(i) - 15.9)) * \text{ProdWeight}(j,i) * \text{Anvendelse}(j,n)) ;$

Parameter ValueStang(l,n) ;

\$Include ValueStang_43949.txt

Variables

z total profit

Binary Variables

y(l,n) 1 if alternative n is chosen to be produced of pig i with bars;

// y(i,n) 1 if alternative n is chosen to be produced of pig i without bars;

Equations

profit definering af objekt funktion

```

        con(l)    * with bars
//    con1(i)    * without bars
        ;

        profit ..    z =e= sum((l,n), ValueBar(l,n)*y(l,n)) ;
//    profit ..    z =e= sum((i,n), ValuePig(i,n)*y(i,n)) ;

        con(l) ..    sum((n),y(l,n)) =e= 1 ;
//    con1(i) ..    sum(n,y(i,n)) =e= 1 ;

```

```

Model begraensninger_v11 /all/ ;
Solve begraensninger_v11 using mip maximizing z ;

```

Appendix 2 – The overall production flow at the slaughterhouse

